

5. EXAMPLES OF RADIOS USING RF OR IF DIGITIZATION

This section describes several radio receivers (currently existing or in development) employing direct digitization at the RF or IF. Digitization at the IF is becoming increasingly popular. Many radio receivers using this digitization currently are being developed. While direct digitization of the RF is a future design goal, few of these systems are in existence today except perhaps for frequencies below the HF band. In general, since many radio receivers using digitization at the RF or IF are currently in development, information about them is quite difficult to obtain. The receivers discussed below are a small sampling of these systems.

The dynamic signal analyzer is an excellent example of technology that uses direct digitization of the RF. The dynamic signal analyzer digitizes the input signal and provides various processing, display, and data storage options. A common signal-processing function is performing an FFT on an input signal and thereby providing a frequency domain display of the input signal. The HP 3587S is an example of this type of analyzer. This particular signal analyzer is implemented as a VXIbus system; the VXIbus is a standard modular instrument architecture that allows custom configuration of various measurement devices in a compact frame under computer control. The configuration of the HP 3587S includes a 10-Msample/s, 18-bit digitizer. This high-resolution ADC provides a maximum SFDR of 110 dB. An amplifier is used before the digitizer to set the system (random) noise power slightly above the quantization noise power. The system noise figure is then determined by this amplifier and is specified to be 14 dB. The signal analyzer contains a DSP module that can compute 250 MFLOPS. With this processor, a 1-MHz real-time bandwidth is achieved [42].

The HP1486A is a VXIbus signal-processing module currently in development that can process 9 billion math operations per second. It achieves this high processing speed by using application-specific integrated circuits (ASIC's) along with performing computations as 28-bit fixed-point arithmetic. This module was designed for communication signal processing and can provide high-speed demodulation of both analog and digital communications signals. Processing speed is claimed to be fast enough to provide real-time demodulation of signals in the proposed HDTV digital transmission format. The HP1486A accepts data input up to 30 Msamples/s using a high-speed local bus. The receiver functions it can perform include: fixed and adaptive filtering; downconversion; extraction of signal amplitude, phase, and frequency information; resampling; adaptive clock and carrier synchronization; and symbol decoding. A general purpose DSP block is also available for more customized processing. These functions are individually programmable and can be used in a wide variety of combinations to implement various types of radio receivers [43].

A few years ago, the Novotel Communications Corporation (Calgary, Canada) was working on a global positioning system (GPS) receiver at 1.575 GHz using direct digitization of the RF. In addition to the challenges presented by direct digitization at this input frequency, the receiver design needed to be small, lightweight, inexpensive, and consume little power. A receiver using bandpass sampling techniques was considered; however, Novotel found that the receiver design was not feasible from a cost standpoint. Additionally, a sample-and-hold amplifier that would perform well at 1.575 GHz was not available commercially at that time so the technical feasibility was also in question.

The Honeywell Technology Center is developing an integrated avionics radio that digitizes and processes wideband IF signals between 100 and 1300 MHz [44]. The frequency bands that the system operates over include:

- 108-118 MHz VHF Omni Range and Instrument Landing System (ILS) Locator
- 118-137 MHz VHF Voice (Including Air Traffic Control Operations)
- 329-335 MHz Instrument Landing System Glide Path
- 960-1215 MHz Electronic Aids to Air Navigation (DME/Mode S)

Postdigitization filtering is used to isolate individual signals along with proprietary hardware to extend receiver dynamic range. Due to the developmental nature of this system, any further details (such as the IF bandwidth, dynamic range, sampling rate, ADC, processor hardware, and types of processing) are considered proprietary.

The SEA Corporation currently is producing a portable handheld transceiver operating in the 220- to 222-MHz band that uses digitization at the IF. SEA also is developing receivers for various applications in the 3- to 30-MHz band [45]. The 220- to 222-MHz band has 5-kHz channel bandwidths and therefore, requires sophisticated modulation techniques that generally depend on digital signal processing. Amplitude-companded single-sideband modulation (ACSSB) is being utilized with transmit tone in band (TTIB). However, discussions are underway to migrate to digital modulation. These receivers digitize IF signals at bandwidths slightly greater than the channel, and use bandpass sampling techniques for further downconversion. The system uses a 12-bit digitizer with a predigitization, 20-dB step AGC device.

Due to the very high dynamic range of input signal amplitudes present in the HF band, and limitations in the SFDR of high-speed ADC's currently available commercially, direct digitization at the RF in HF receivers is currently unrealistic [2]. There has been some recent activity, however, in digitization of the IF in HF radio receivers. An example design for an HF SSB radio receiver employing digitization at the IF is described in [10]. This SSB receiver uses a traditional superheterodyne front-end with two conversion stages to generate a 16-kHz wide IF signal centered at 456 kHz. An ADC, operating in a bandpass-sampling mode, samples the IF signal at 96 kHz thereby translating the desired replica of the spectrum to an IF centered at 24 kHz. Digital signal processing is then used to convert the IF signal to a baseband signal with an in-phase and quadrature-phase component. Decimation is then used to reduce the sample rate and allow the signal processing to take place in real time. The SSB signal is then digitally demodulated and converted to an analog signal for output.

Digitization at the wideband IF is being used in some receivers for cellular and PCS base stations. A potentially large market exists for these types of receivers. One example base station, the Watkins-Johnson Base₂, uses a receiver that digitizes at the wideband IF. The Base₂ base stations can be used for cellular or PCS applications by simply interchanging the RF front-end. The receiver in the Base₂ base station performs an initial downconversion and then digitizes up to a 15-MHz bandwidth at the IF. Digital signal processing is then used for channelization, filtering, tuning, and demodulation. The capability of digitizing up to a 15-MHz bandwidth permits digitization of either the entire mobile-to-base station cellular frequency block A or block B with a single receiver. Digitization of an entire, licensed, mobile-to-base station PCS frequency block

also can be achieved. The Steinbrecher and Airnet Corporations also produce cellular and PCS base stations that use wideband IF digitization.

There are several advantages of receivers in cellular or PCS base stations that digitize the wideband IF over traditional receivers used in analog cellular base stations. First, analog cellular base stations require one receiver per cellular channel. Only one wideband receiver is required for all of the cellular channels in a cell using a nonsectorized cell. Sectorized cells require one wideband receiver for all of the cellular channels used in a sector. Because of this, receivers that digitize at the wideband IF are cheaper, smaller, and consume less power than analog receivers in cellular base stations. Since filtering, demodulation, and signal processing are all performed digitally, the audio quality is claimed to be better than in analog receivers [46]. Perhaps one of the greatest advantages is that the receivers can receive multiple telephone calls with differing air-interface standards simultaneously. The receiver can be reconfigured with software and can operate with any air-interface standard. These standards include the advanced mobile phone service (AMPS), narrowband AMPS (N-AMPS), time-division multiple access (TDMA), cellular digital packet data (CDPD), and code-division multiple access (CDMA) [47].

Speakeasy is a new, joint-service military radio transceiver currently in development whose receiver uses digitization at the IF. The project is being managed by the Air Force Rome Laboratory. In Phase I of this project, the Speakeasy concept was demonstrated by implementing a VME-based radio operating over 2- 2000 MHz using digitization of the IF at bandwidths up to approximately 10 MHz. General purpose, programmable DSP's were used for radio receiver operations whenever possible. When general-purpose DSP's were not fast enough to perform certain operations, application specific processors and dedicated digital hardware were used.

Two general modes of operation are available for the VME-based Speakeasy radio: a narrowband mode where an approximately 200-kHz IF bandwidth is digitized, and a wideband mode where an approximately 10-MHz bandwidth is digitized. Currently, two separate ADC's are used for these two modes. The narrowband mode uses a high-resolution ADC while the wideband mode uses a lower-resolution, faster ADC. The eventual goal is to use only one ADC for both modes when ADC's of sufficient resolution and sampling rate become available.

The VME-based Speakeasy radio allows selection (from a menu) of the types of signals that a user wants to transmit and receive. Currently, up to two types of signals can be processed (received or transmitted) simultaneously. The ultimate goal is to provide a capability to process four types of signals simultaneously. Speakeasy can process various types of amplitude, frequency, and phase-modulated signals as well as spread spectrum signals for analog and digital voice and data communication.

The goal of Phase II of the Speakeasy project is to provide a more compact and enhanced version of the VME-based radio developed in Phase I that will emulate more than 15 existing military radios [48].

Both direct broadcast satellite (DBS) and digital audio broadcast (DAB) systems transmit various forms of digitally modulated signals. Receivers for these systems can use either traditional demodulators (employing analog circuitry) after downconversion to IF, or digitization at the RF

or IF before demodulation. Traditional demodulators require no analog-to-digital conversion before demodulation. When using digitization at the RF or IF, demodulation is performed using a digital signal processor or dedicated digital-processing hardware.

The Advanced Wireless Technologies AWT2002 is a variable data rate BPSK/QPSK demodulator on a single IC. It is designed to operate on IF signals that have been digitized with a 6-bit ADC. Demodulation is accomplished digitally in this IC as opposed to demodulation requiring analog circuitry. The currently available version of this IC operates at a 2-Msymbol/s rate; however, a future version targeted for DBS systems will support symbol rates up to 31.5 Msymbols/s. Digitization at the RF or IF and then digital demodulation, like that provided by the AWT2002, may prove to be very useful in applications such as DBS and DAB.

Digitization at the RF or IF can be employed by receivers in radio propagation measurement systems. One example of a receiver that uses digitization at the wideband IF is in the recently patented digital sampling channel probe (DSCP). The DSCP was developed in a joint effort between the Institute for Telecommunication Sciences and Telesis Technologies Laboratory, Inc. The probe is ideal for making outdoor impulse response measurements to characterize wideband propagation in the radio channel [49].

The DSCP operates by transmitting an RF carrier modulated by a PN code over a radio propagation channel. The transmitted signal, modified by the propagation channel, then is received, downconverted to an IF, and digitized. After digitization at the IF, the complex impulse response of the radio propagation channel is generated via digital signal processing. Digitization at the IF enables the DSCP to measure an impulse response much faster than the traditional analog sliding correlator probe. This allows better characterization of rapidly changing propagation channels.

Many different system configurations are available with the DSCP. Current configurations use commercially available equipment such as RF signal generators, spectrum analyzers, digital oscilloscopes, and personal computers to achieve a high degree of flexibility and to minimize system setup time for specific field studies. Both the transmitter and receiver have a dual-channel capability allowing for transmission and reception with various combinations of two different PN codes, carrier frequencies, antenna polarizations, and antenna spacings. While the DSCP typically has been used to make impulse response measurements around 900 and 1850 MHz, it can be configured to accommodate measurements over an even broader range of frequencies.

In the typical configuration, the null-to-null bandwidth of the probe is 20 MHz, providing a delay resolution of 100 ns and a maximum measurable delay of 51 μ s. The probe can be configured easily for wider bandwidths (finer time resolution) and different maximum delays. Recent improvements to the probe include the ability to measure absolute time and Doppler spread. Future plans include expanding the probe to multiple channels to help analyze the potential benefits of advanced antenna systems and antenna signal processing [49,50].

6. SUMMARY AND RECOMMENDATIONS

The key factors in radio receivers where digitization occurs at the IF or RF are analog-to-digital conversion and digital signal processing. Although not discussed in this paper, digital-to-analog conversion is also a factor for applications requiring analog output (such as voice). Because of the rapid advances in hardware development of ADC's, DAC's, digital signal processors, and specialized IC's, development of radio receivers using digitization at the IF (and in some cases at the RF) is becoming increasingly popular.

Hardware limitations of ADC's, digital signal processors, and DAC's place constraints on digitization at the IF and RF in radio receivers. It was shown that digitization at the RF, in general, requires some type of bandlimiting (filtering) and amplification before the actual digitization takes place. The required amount of filtering and amplification is application-specific. ADC performance is improving rapidly. However, there is a tradeoff; one can get either high sampling rates or high resolution, but not both simultaneously. Therefore, the high sampling rate ADC's required for wide bandwidth applications may not have sufficient SFDR. Digitization at the RF is now being considered for satellite receivers since a large SFDR is not a necessity, very high sampling rate ADC's already exist, and even faster ADC's are being developed. For receiver applications requiring a large SFDR, such as HF communications, digitization at the IF is currently a more practical option.

Digital signal processors may present an even greater limitation than ADC's in radio receivers using digitization at the RF or IF. The speed, size, and cost of these processors are important for a particular radio receiver application. The requirement for real-time operation for many radio receivers places a heavy burden on these processors. It is difficult to discuss limitations of digital signal processing in general terms since many algorithms can be implemented in radio receivers depending on the specific application. The amount of time that signal processing requires is a function of the bandwidth of the signal, the speed of the processor, and the number and complexity of the algorithms required to perform the needed radio receiver functions.

Several potential methods and devices that are expected to be useful in radio receivers employing digitization of the RF or IF are discussed in this report. Various types of quantization techniques include uniform, μ -law, adaptive, and differential quantization. These techniques can be used to improve the dynamic range of ADC's as well as make the SNR insensitive to input signal amplitude. Nonlinear compression devices such as log amplifiers and automatic gain control amplifiers also can be used to improve the dynamic range of ADC's. Postdigitization algorithms for improving the SFDR provide extended dynamic range for presently available ADC's. Sampling downconverters, based on the theory of bandpass sampling, may be coupled with ADC technology to provide improved ADC performance for bandpass sampling applications. Specialized IC's for digital signal-processing tasks required in radio receiver applications show great potential in increasing processing speed; this allows more receiver functions to be executed in real time. Bandpass sampling is expected to be important for radio receiver applications since it allows the use of more readily available ADC's with lower sampling rates and higher SFDR.

This report provides information on receivers implementing digitization at the RF or IF. The topic of EMC analysis for these radio receivers needs to be investigated further. Due to the

tremendous variety of possible receiver implementations employing digitization at RF or IF, focusing on some specific RF front-end configurations probably would be the best approach for determining EMC analysis procedures. In general, however, RF front-end specifications such as SFDR and intermodulation distortion should be important, just as in EMC analyses of traditional receivers not employing digitization of the RF or IF.

The potential for spectrum overlap due to the sampling process is probably the major difference between receivers that employ digitization at the RF or IF and those that do not. Effects of this spectrum overlap are best determined by considering the specific radio system details such as the type of source information (i.e., voice, data, or video); desired signal bandwidth; modulation and coding techniques; undesired signal characteristics (bandwidth, power, and type of signal); and the performance criterion used to evaluate the quality of the reception of the desired signal. The sampling rate in relationship to the maximum frequency content of the signal and the signal bandwidth is of utmost importance in evaluating spectrum overlap. Computer simulation is probably the best tool available to evaluate the effects of spectrum overlap on receiver performance.